A1-Architecture-based self-adaptation

INF9360

Seminar on dependable and adaptive distributed systems

(Slides has some derived contents from various sources)

Papers to present

- An Architecture-Based Approach to Self-Adaptive Software
  - By P. Oreizy, M. Gorlick, R. Taylor, D. Heimbigner, G. Johnson, N. Medvidovic, A. Quilici, D. Rosenblum, and A. Wolf, IEEE Intelligent Systems. May-June, 1999

- Rainbow: Architecture-Based Self-Adaptation with Reusable Infrastructure
  - By David Garlan, Shang-Wen Cheng, An-Cheng Huang, Bradley Schmerl, Peter Steenkiste, IEEE Computer Society, pp. 46-54, October, 2004

An Architecture-Based Approach to Self-Adaptive Software

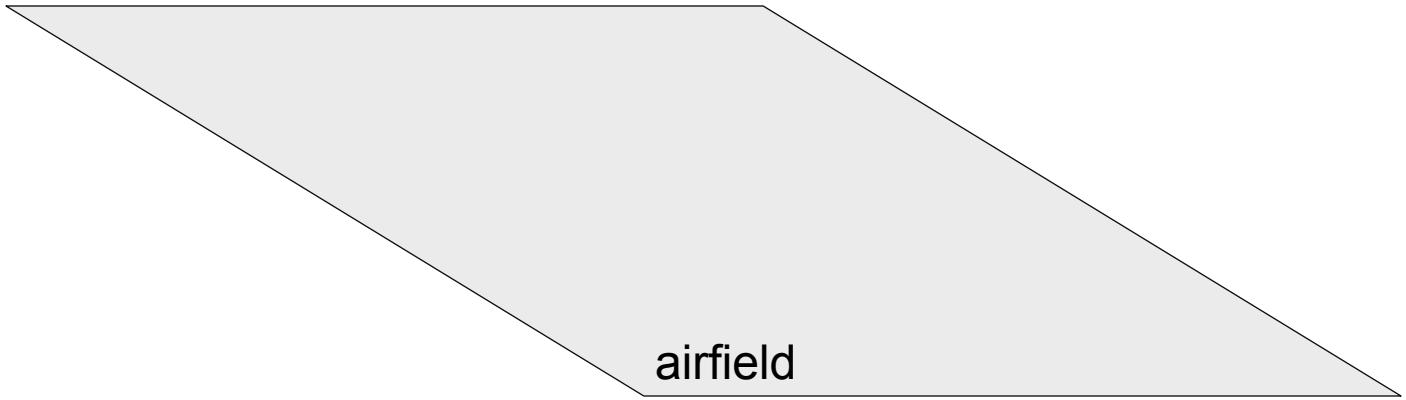
- Discuesses the fundamental role of software architecture in self-adaptive systems
- Topics covered:
  - Self-adaptive software introduction
  - Degrees of self-adaptability
  - Dynamic Software architecture definition
  - Adaptation management

Sample scenario

mission: fleet of unmanned air vehicles
to disable an enemy airfield

replan their mission, dividing
into two groups: SAM-suppression and airfield-suppression

surface-to-air missile (SAM)
launchers now guards the airfield



What happened

- Specialized algorithms for **detecting** and recognizing SAM launchers.
- Replannning by **Analyses** that include feedback from new situation.
- **New software** components are dynamically loaded and integrated without requiring restart, or any downtime.
- Taking place **autonomously.**

Self-adaptive software

- Definition:

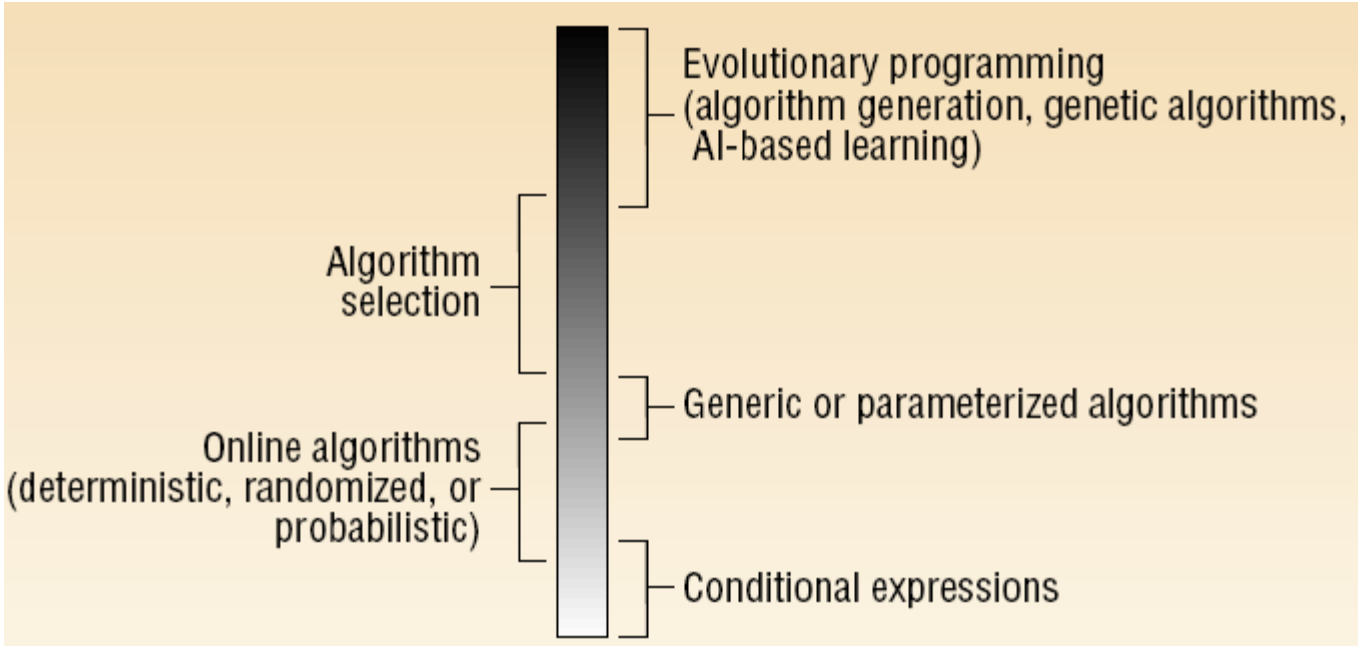
> Self-adaptive software is a software that modifies its own behavior at run-time in response to changes in its operating environment

- **Behavior**: anything the software is expected to do
- **Run-Time**: do not need to be shut down to make the change
- **Changes in operating environment**: anything observable by the software system, e.g. end-user input, external hardware devices and sensors, or program instrumentation

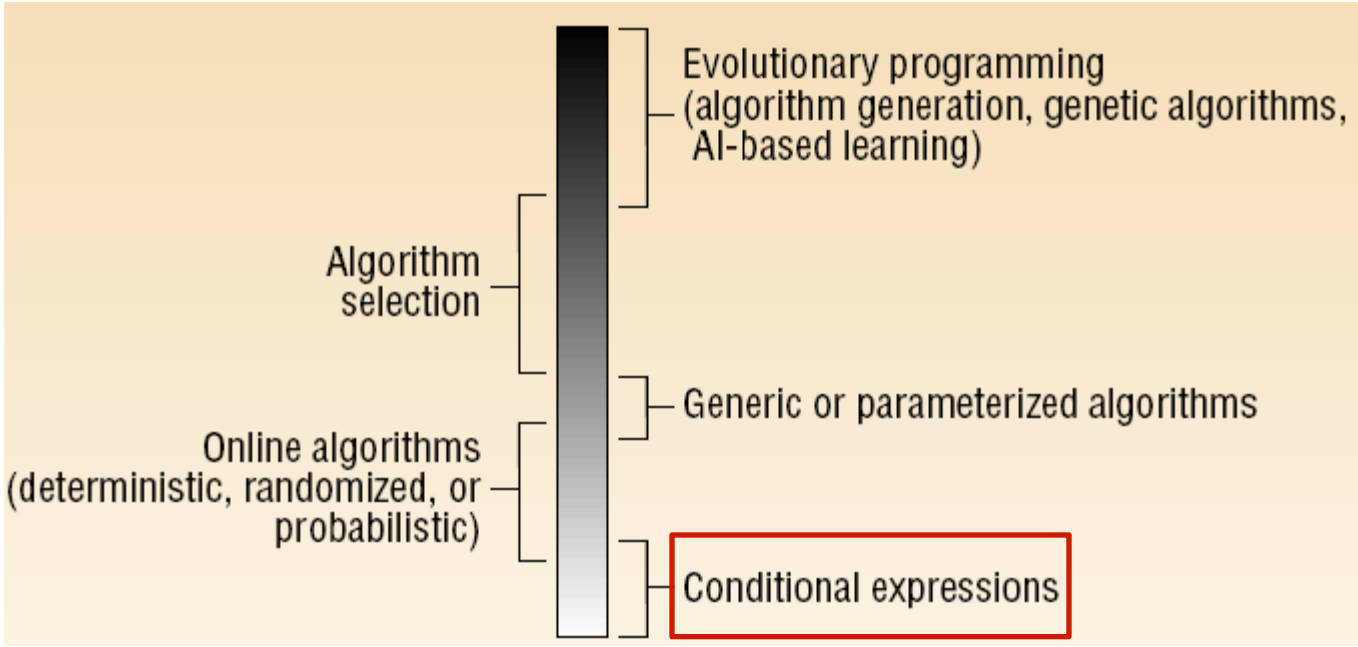
Issues for adaptation

- What Conditions?
  - Performance boost, failure recovery, re-configuration
- Open or Closed adaptation
  - Is new application behavior can be added at runtime?
- Type of autonomy
  - Fully autonomic, Self-contained, Human-in-the-loop
- Frequency
  - Opportunistic, continuous, or lazy, as needed
- Cost Effectiveness
  - Benefits should outweigh the cost of adaptation
- Information Type and Accuracy

Degrees of adaptability

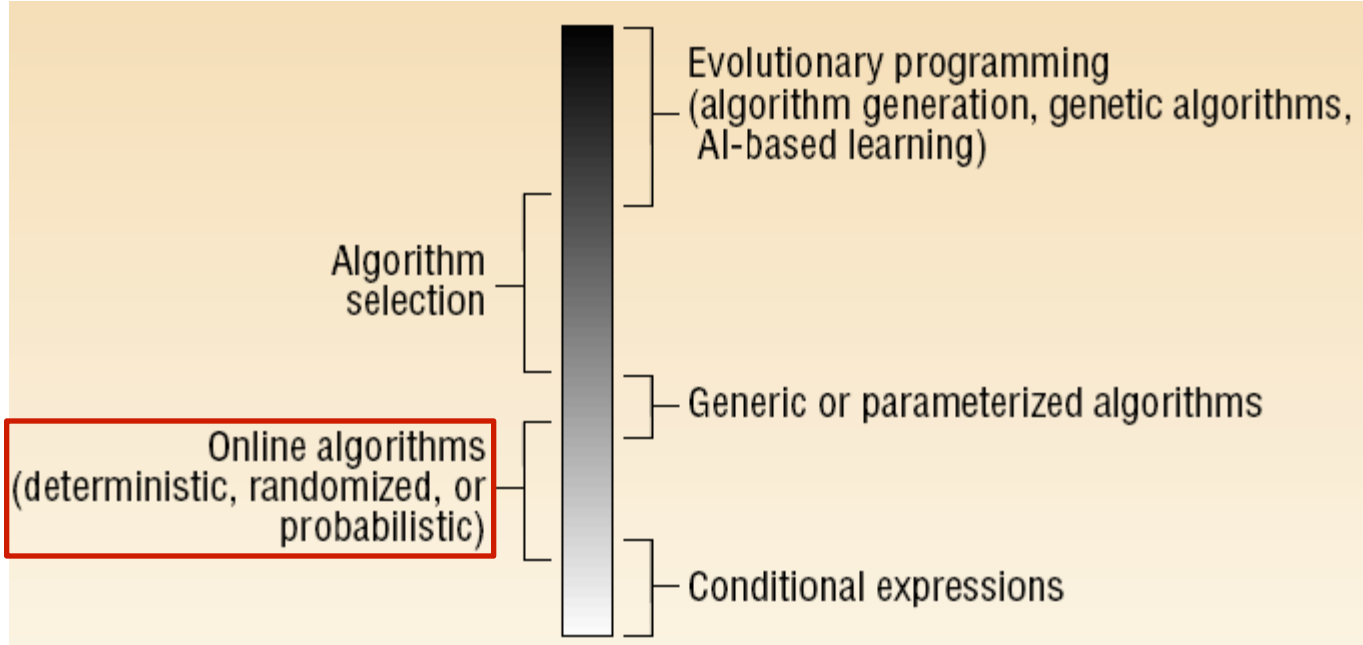


Conditional expressions



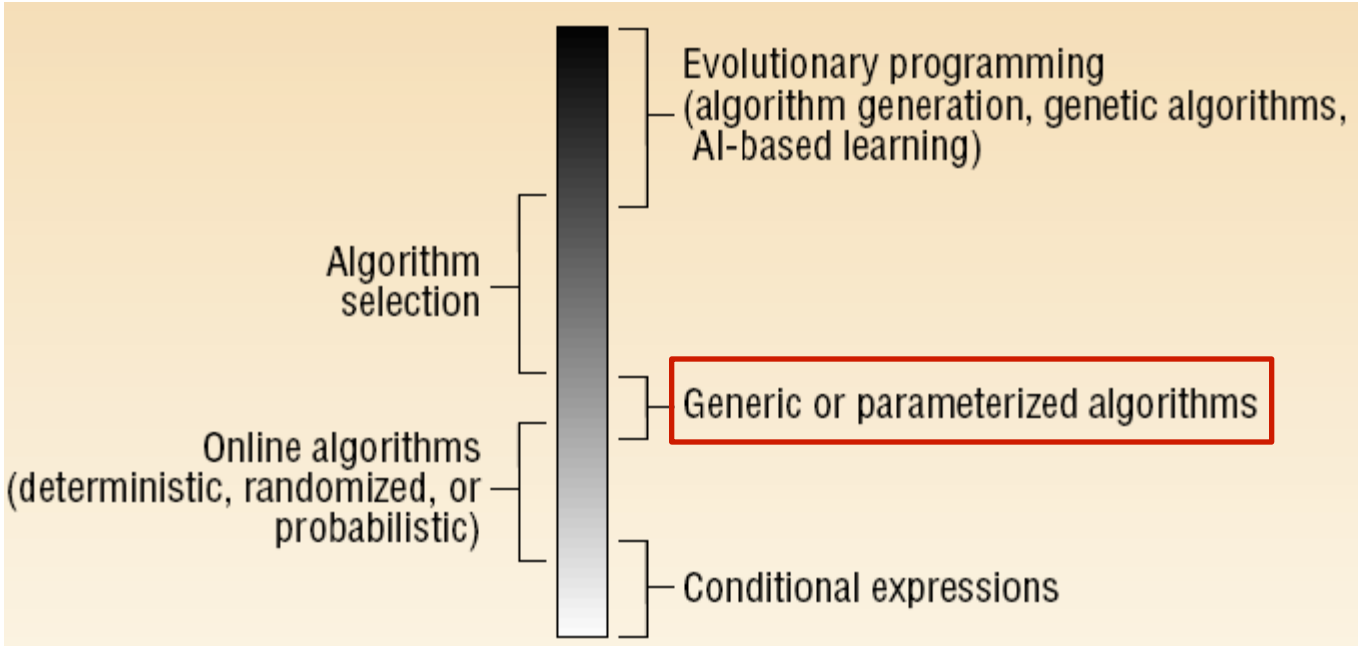
- Program evaluates an expression and alters its behavior based on the outcome
- E. g. *if/switch statements*

Online algorithms



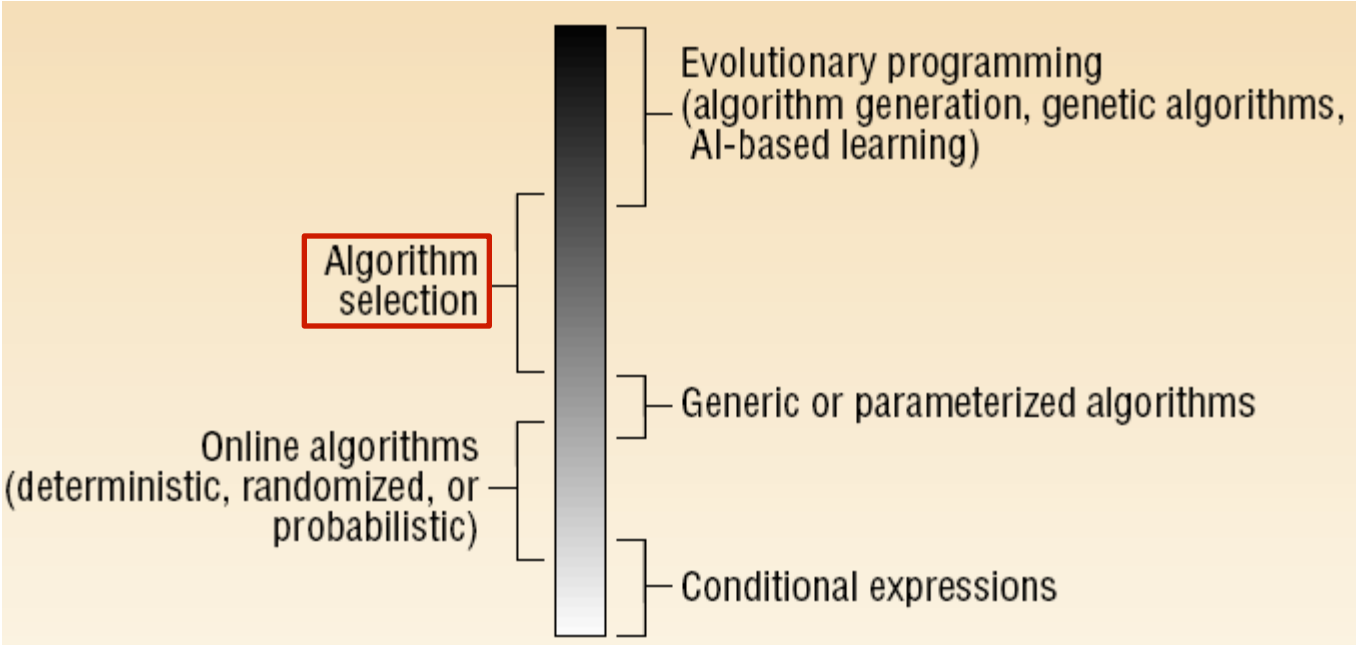
- assume future events are uncertain
- leverage knowledge about the problem and the input domain to improve efficiency
- E. g. memory-cache paging algorithm

Generic algorithms



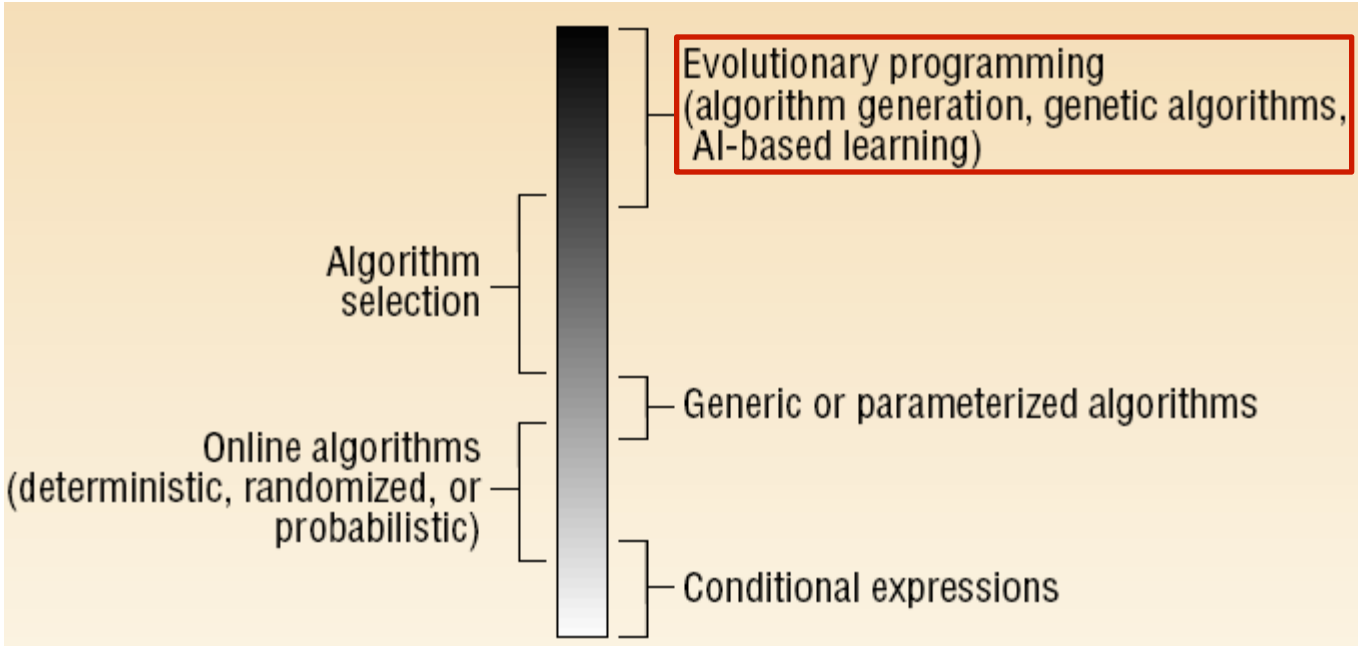
- Provide behaviors that are parameterized
- E.g. polymorphic type in OOPLs, working with instances of new classes (derived from known classes or implement known interfaces)

Algorithm selection



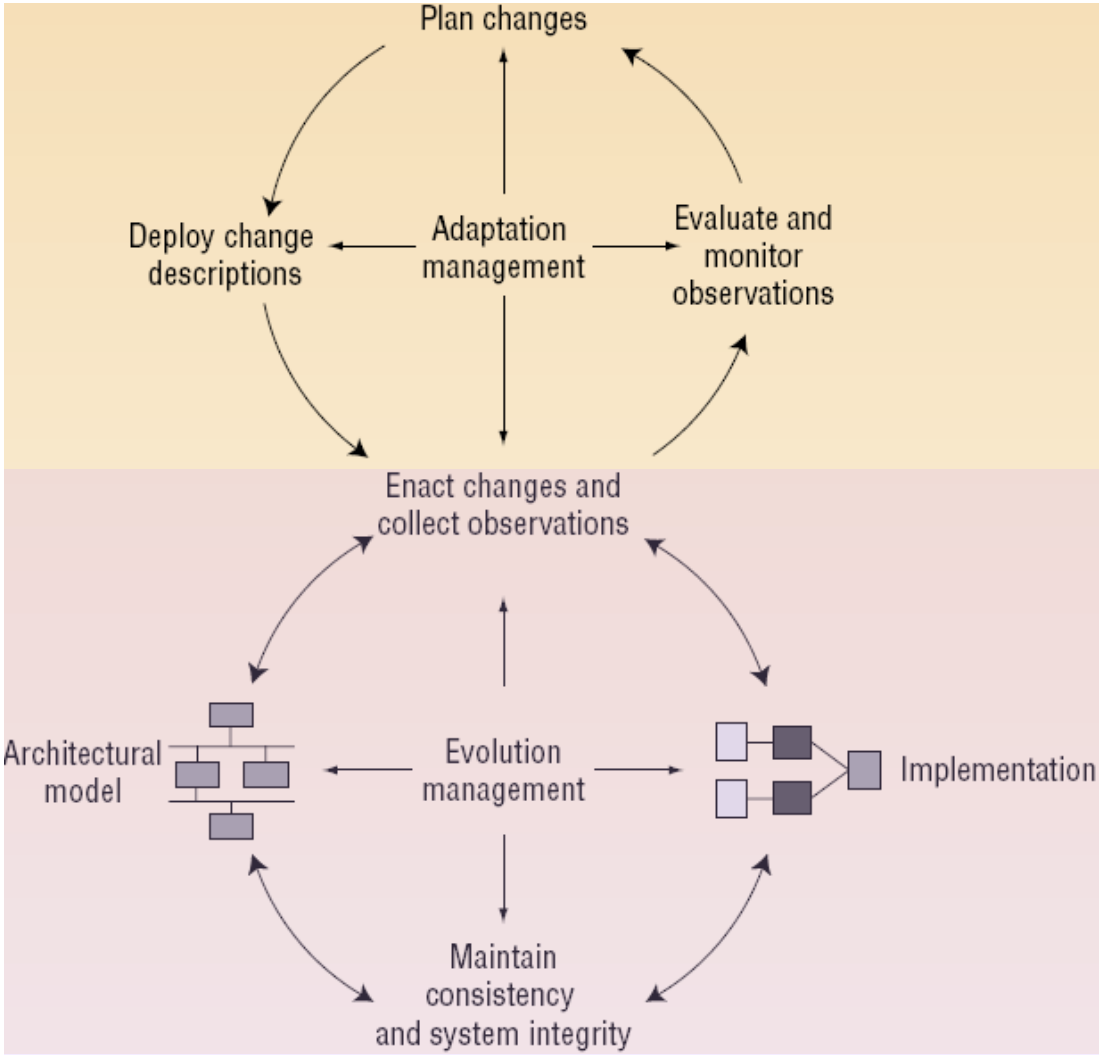
- Selection of the effective algorithm among a fixed set of available algorithms based on environment properties
- E. g. Self optimizing compiler uses program-profiling data collected during program execution to select another optimization algorithms

Evolutionary programming

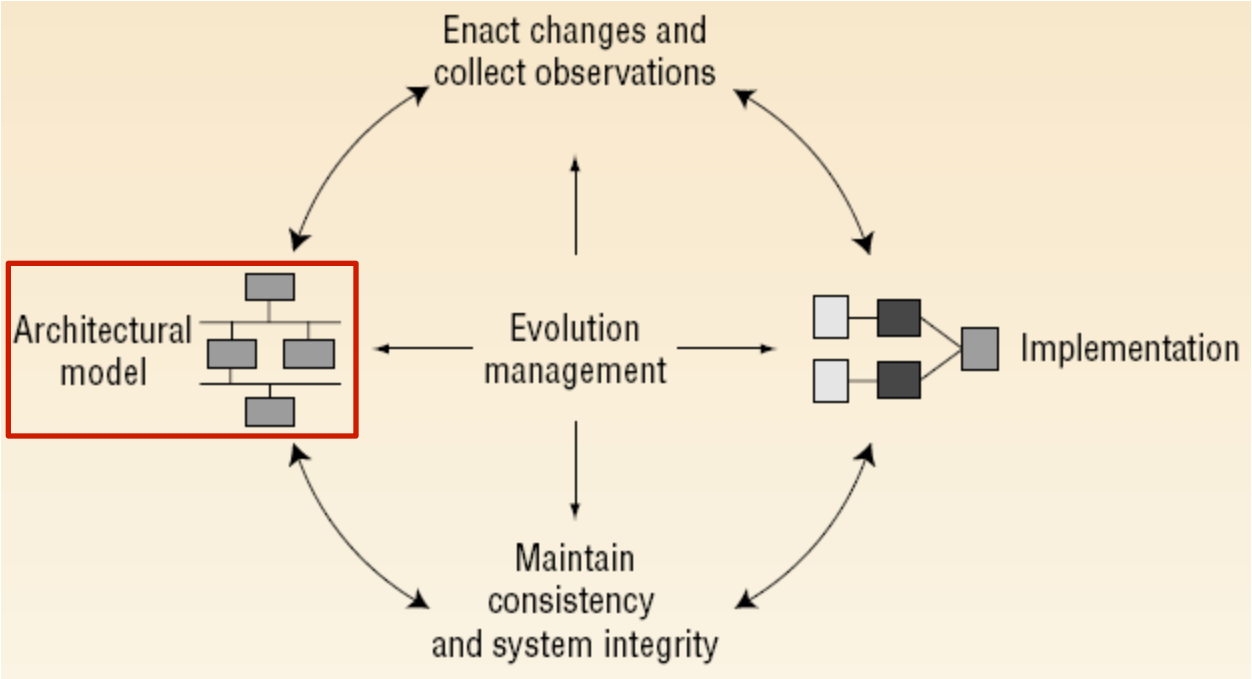


- Using properties of the operating environment and knowledge gained from previous execution to generate new algorithms

Adaptation methodology



Architectural model



Architecture-driven development

- From Architectural model to Implementation
- Consistency between model and Implementation
- *System*: network of coarse-grained **components** bound together by **connectors**
- Connectors are transport and routing services for messages or objects
- Components do not know how their inputs and outputs are delivered or transmitted or even what their sources or destinations might be
- Connectors know exactly who is talking to whom and how
- Separating computation from communication

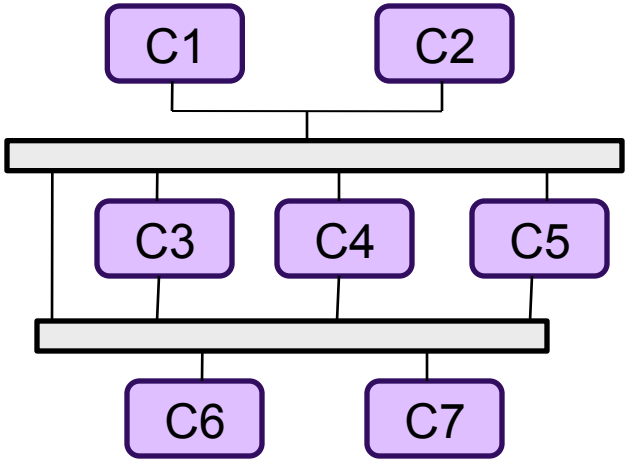
Dynamic software architecture

- In dynamic systems: modification in behaviour at run-time by making the following architectural changes:
  - Adding new components
  - Removing existing components
  - Replacing existing components
  - Changing the connectivity structure between components
- Two approaches to dynamism at the architectural level:
  - C2
  - Weaves

C2 and Weaves

- Both
  - distinguish between components and connectors
  - no restriction on their implementation language
  - communication between components by exchanging asynchronous messages (C2) or objects (Weaves)
  - all communication between components must be via connectors

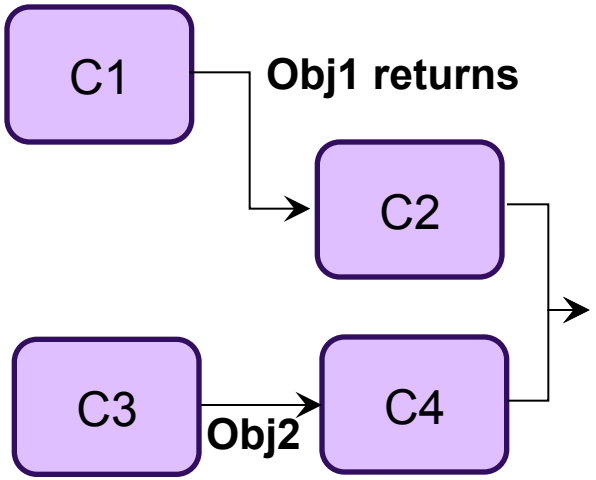
C2



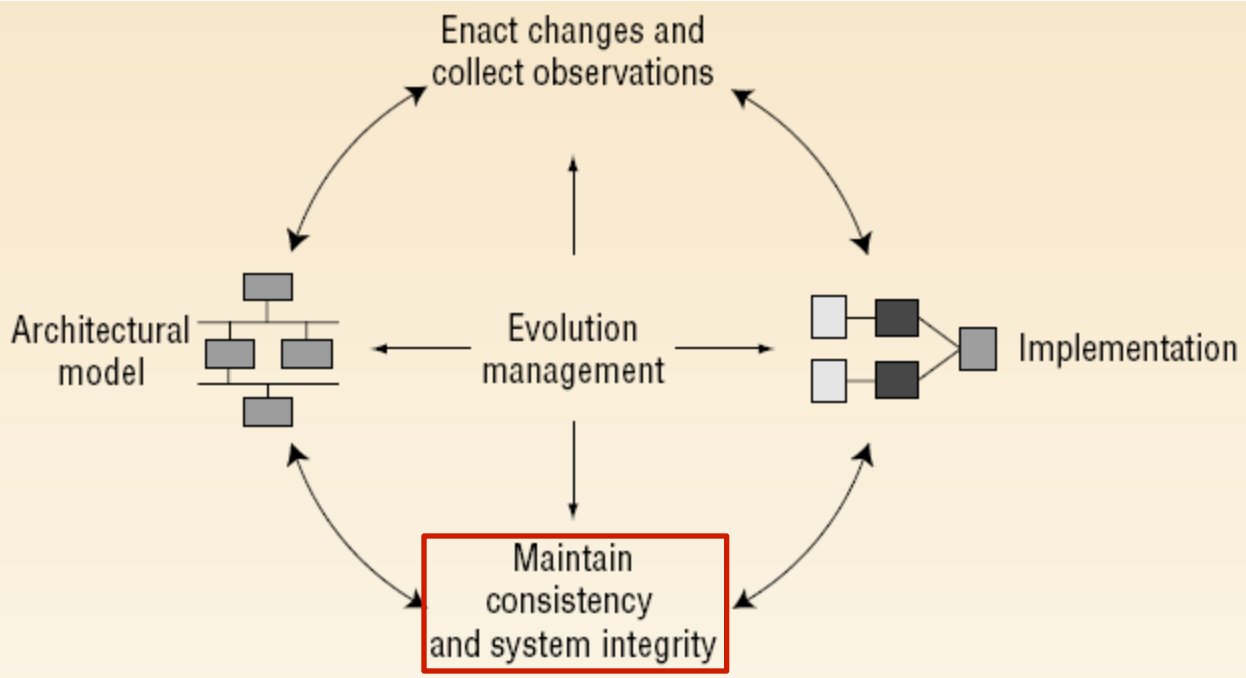
- System as a **hierarchy of concurrent** components bound together by connectors
- Component is aware of components “above” it and unaware of components residing at the same level or “beneath” it
- Communication between a component and those below it is handled implicitly using events
  - Whenever a component changes its state, it broadcasts this to all components below it

Weaves

- Dynamic, objectflow-centric architecture
- Components consume objects as inputs and produce objects as outputs
- Components do not knows the semantics of the connectors that delivered its input objects or transmitted its output objects



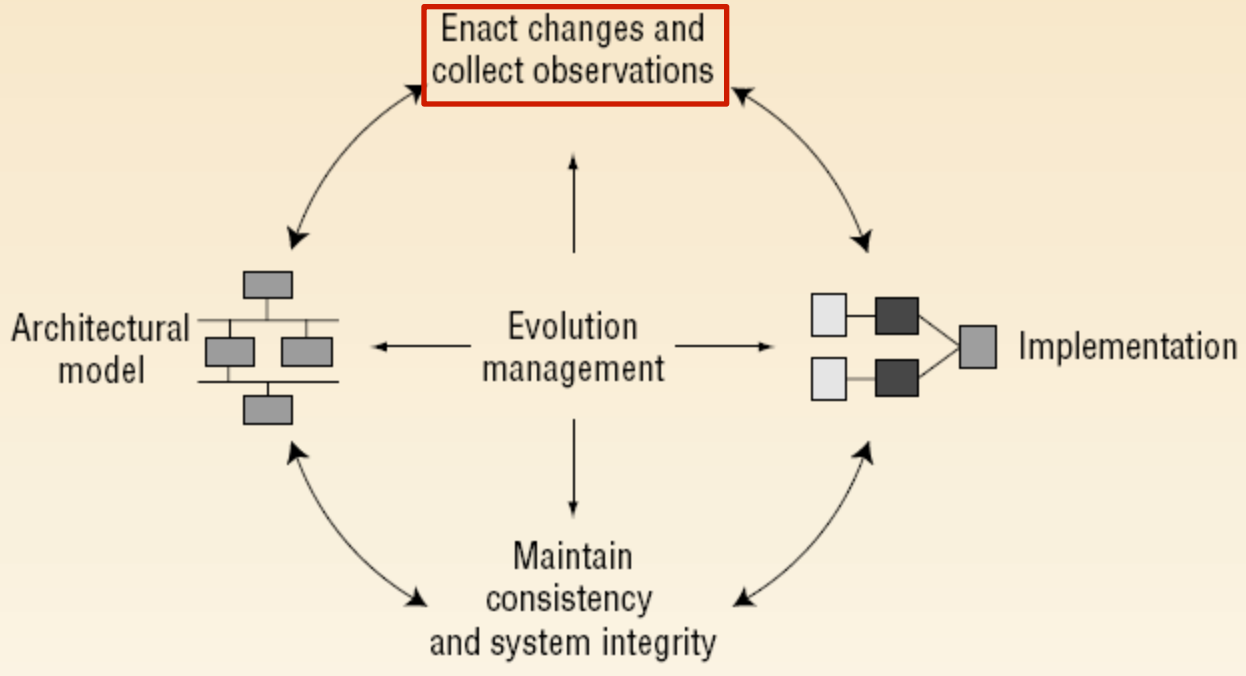
Maintaining consistency



Maintaining consistency and integrity

- Preserving an accurate and consistent model of components and connectors
- Maintain a strict correspondence between the architectural model and the executing implementation
- *Architecture Evolution Manager (AEM)*
  - maintains the consistency between architectural model and implementation
  - prevents changes from violating architectural constraints

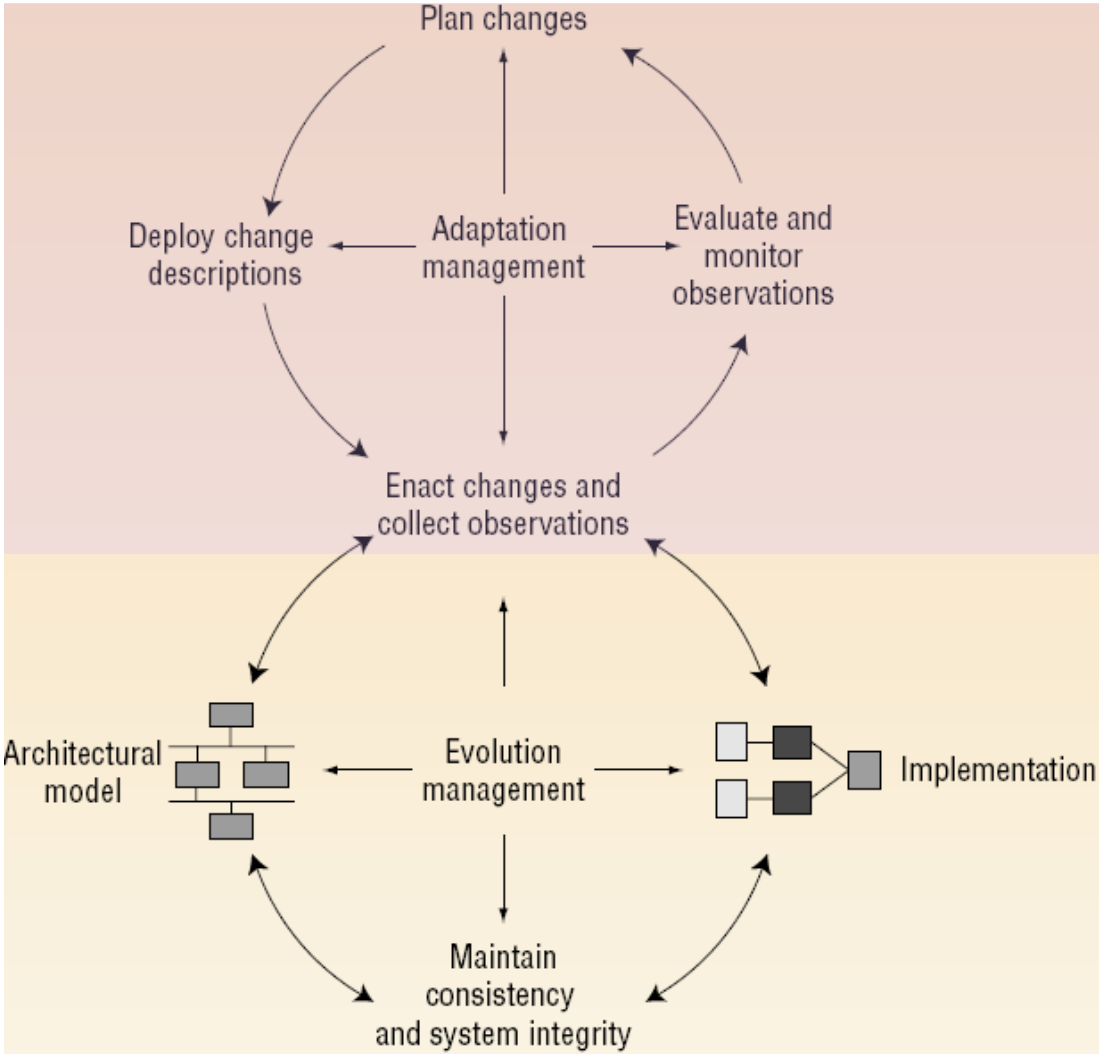
Enacting changes



Enacting changes

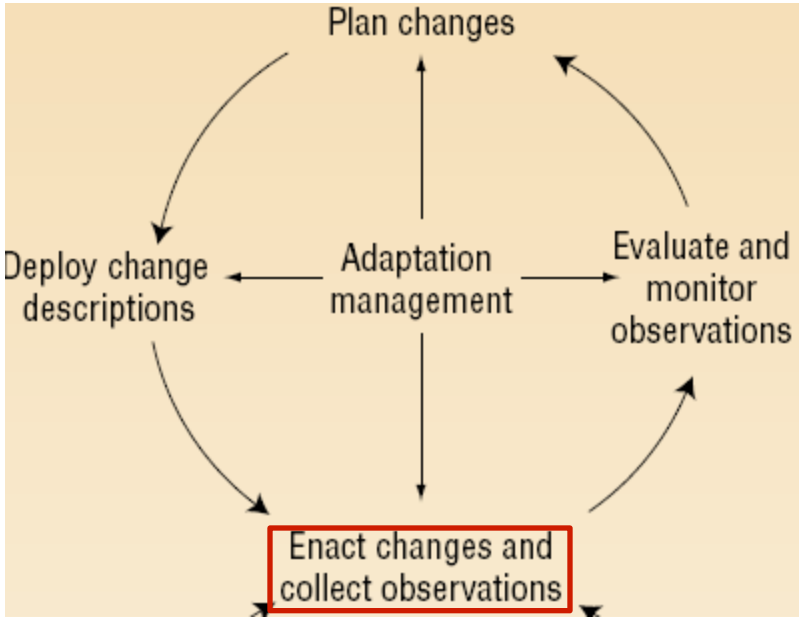
- Possible sources of architectural change
- Architecture editor
  - To construct architecture and describe modifications
  - With analysis tools such as design analyzer or domain-dependent analyzer
- Modification interpreter
  - Tool to interpret change scripts written in a change-description language to primitive actions supported by the AEM

Adaptation methodology



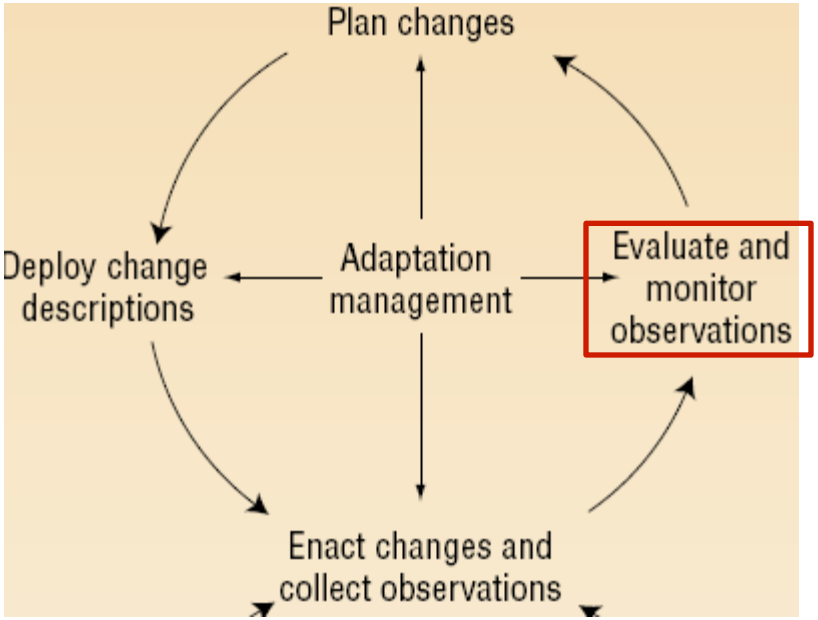
Collecting observations

- Varieties of observations: event generation, …
- *Observers* for notification of exceptional events
- *Expectation agent*
  - detecting and noting single events is not enough
  - responds to the occurrence of event patterns
- New techniques for reducing the monitoring overhead



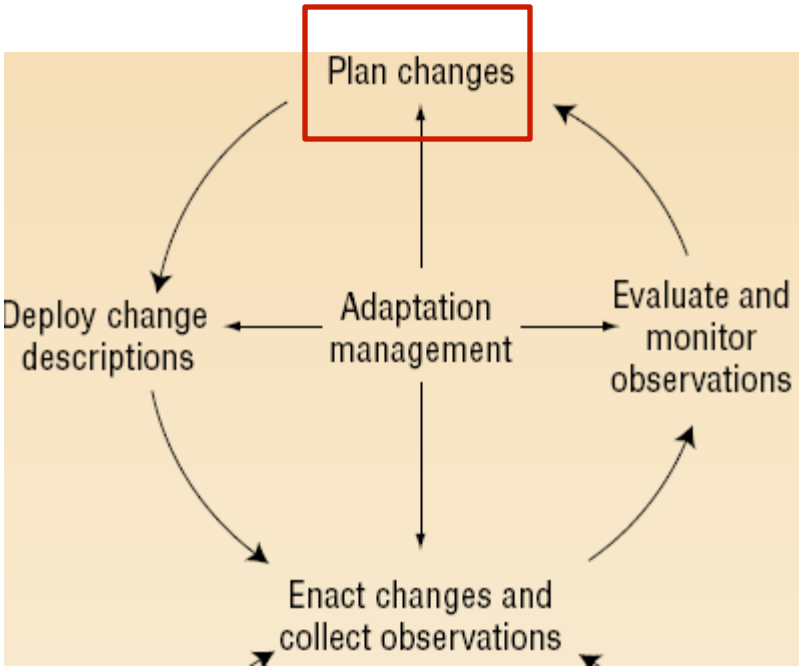
Evaluate and monitor observations

- Adaptive demands arise from inconsistencies or suboptimal behavior
- Evaluating and observing an application's execution, including, performance monitoring, constraint verification, …



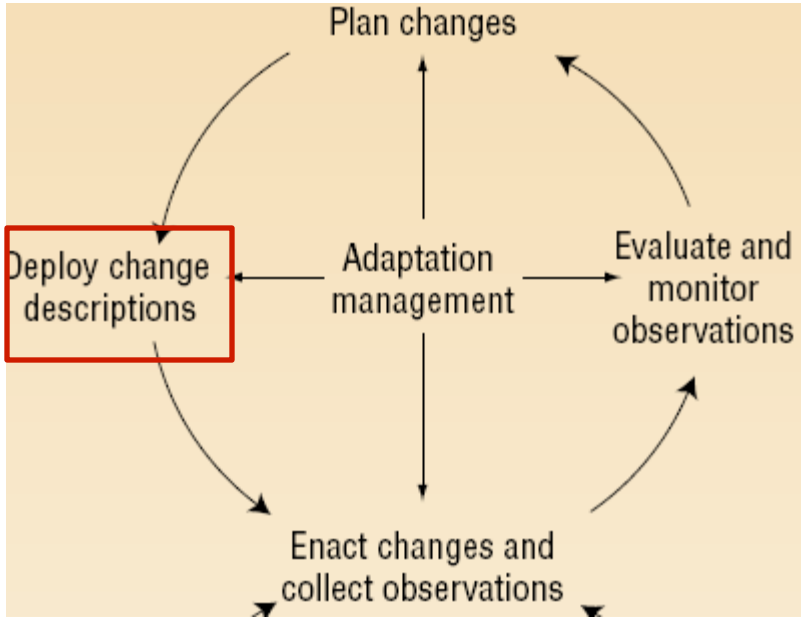
Plan changes

- The task of accepting the evaluations, defining an appropriate adaptation, and constructing a blueprint for executing that adaptation
- Two forms
  - Observation planning: determines which observations are necessary for deciding
  - Adaptation planning: determines exactly which adaptations to make and when



Deploy change descriptions

- Change descriptions
  - Included are any new required components or connectors and their affiliated annotations
  - Interact with the AEM to translates the change in descriptions into specific updates of implementation



Quiz and Summary

- What kind of dynamic architecture model will be most suitable for dynamic link library?
- Answer:
- Does evolution managers directly interfere in architecture editing?
- Answer
- Which programming model (In the spectrum) captures the result of previous execution?
- Answer

Summary

- Paper main goal
  - Introducing an architecture-based approach to managing self-adaptive software
- To achieve this goal
  - Describe dynamic software architecture
  - Explain how architectural model eases software adaptation

Key points

- Software spectrum from self adaptation
- Presented dynamic software architectures: C2 and Weaves
- Making effort to connect software development process with adaptation process

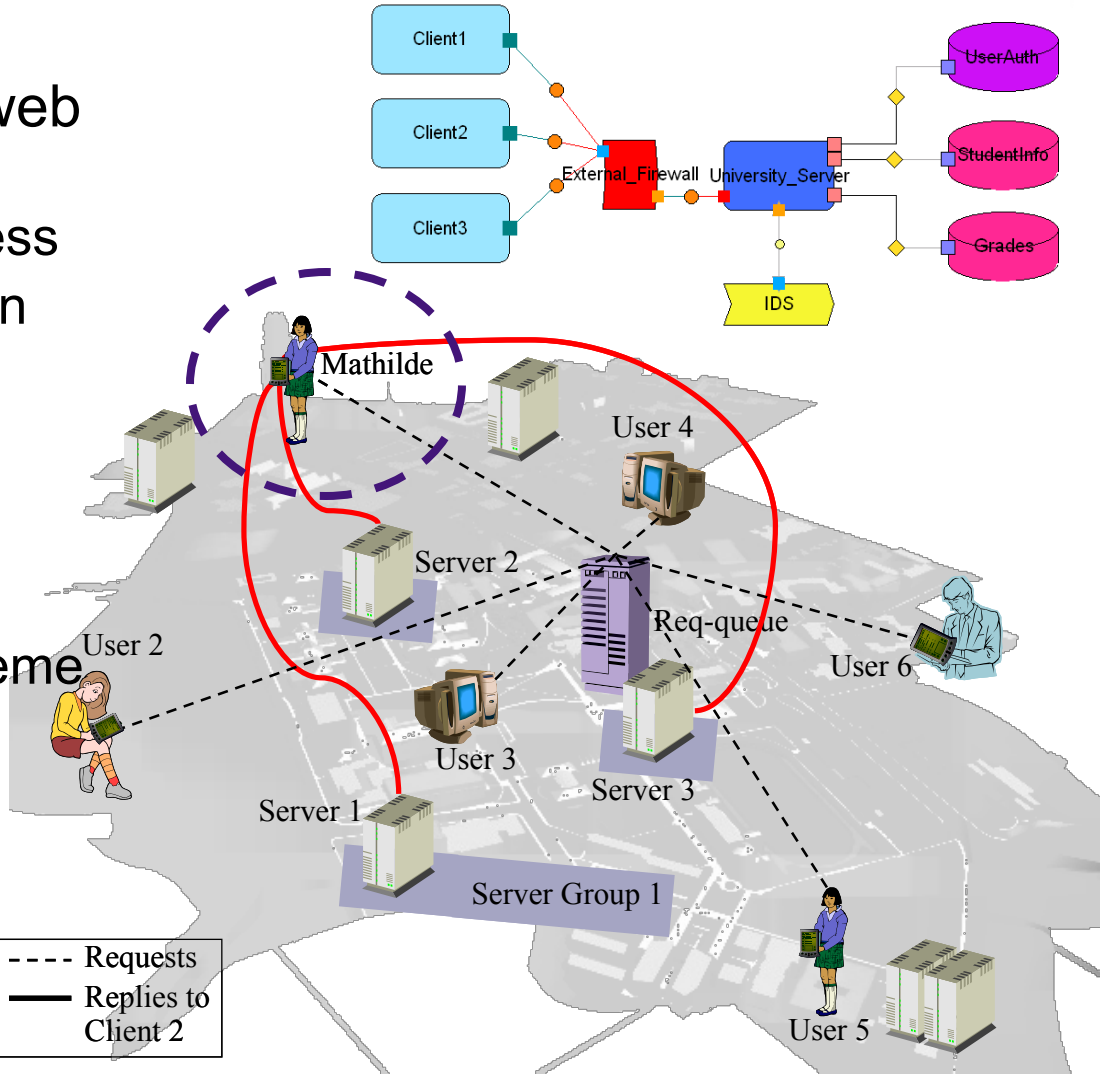
Questions

- Methods for constraint matching?
  - Conditional operator
  - Black box testing: Based on I/O
- Methods for architecture enforcing?
- Difference in the architecture change requirements for the run-time changes and static changes?

Rainbow: Architecture-based Self-adaptation
By David Garlan et al, 2004

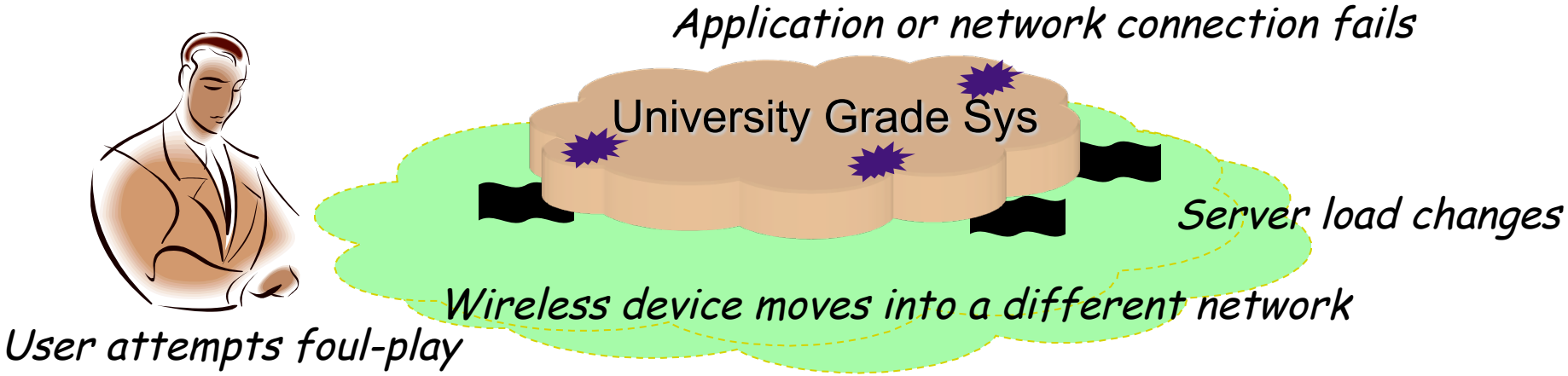
Motivating University Grade System

- Students using university web
  - University aims to provide timely and ubiquitous access
  - One student tries to hack in and change his grades
- Possible (escalating) responses:
  - Turn on auditing
  - Switch authentication scheme
  - Sandboxing
  - Move grades data
  - Close off connections
  - Partition network
  - Turn off services



Many Things Can Go Wrong

- Resource variability
- Changing environments
- Shifting user needs
- System faults



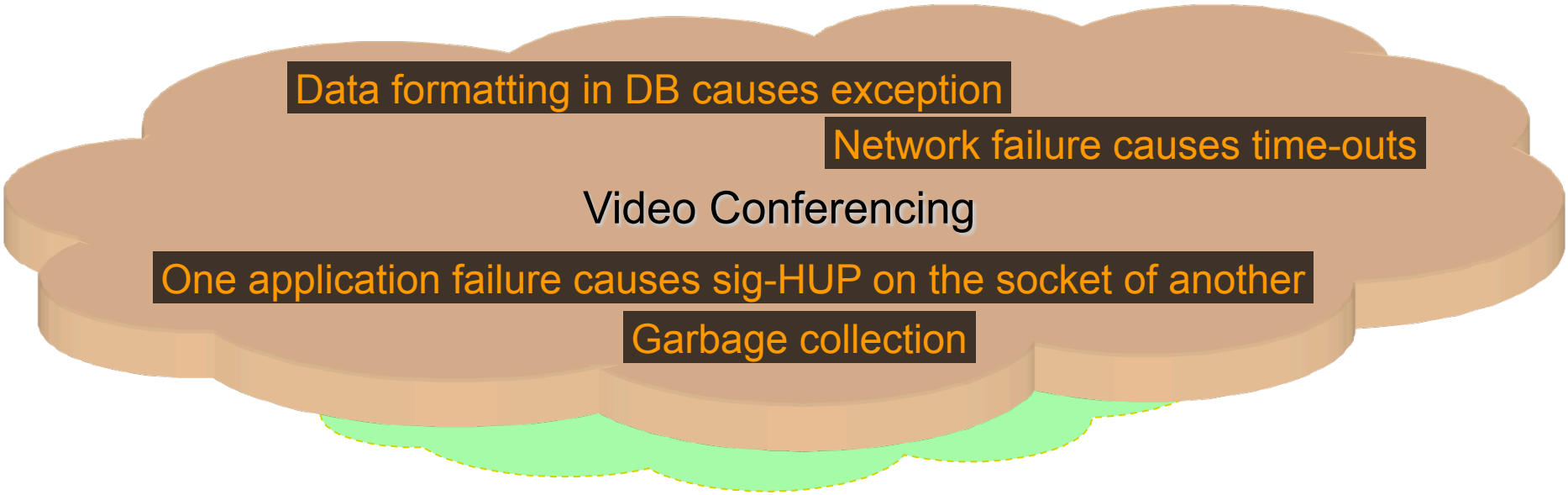
The system should dynamically adapt to these problems.

Traditional, Internal Mechanisms

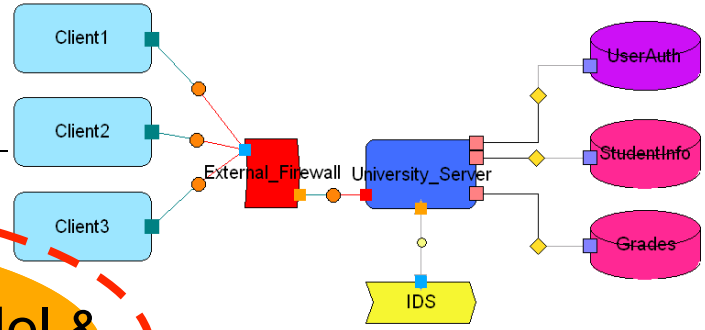
Limitations

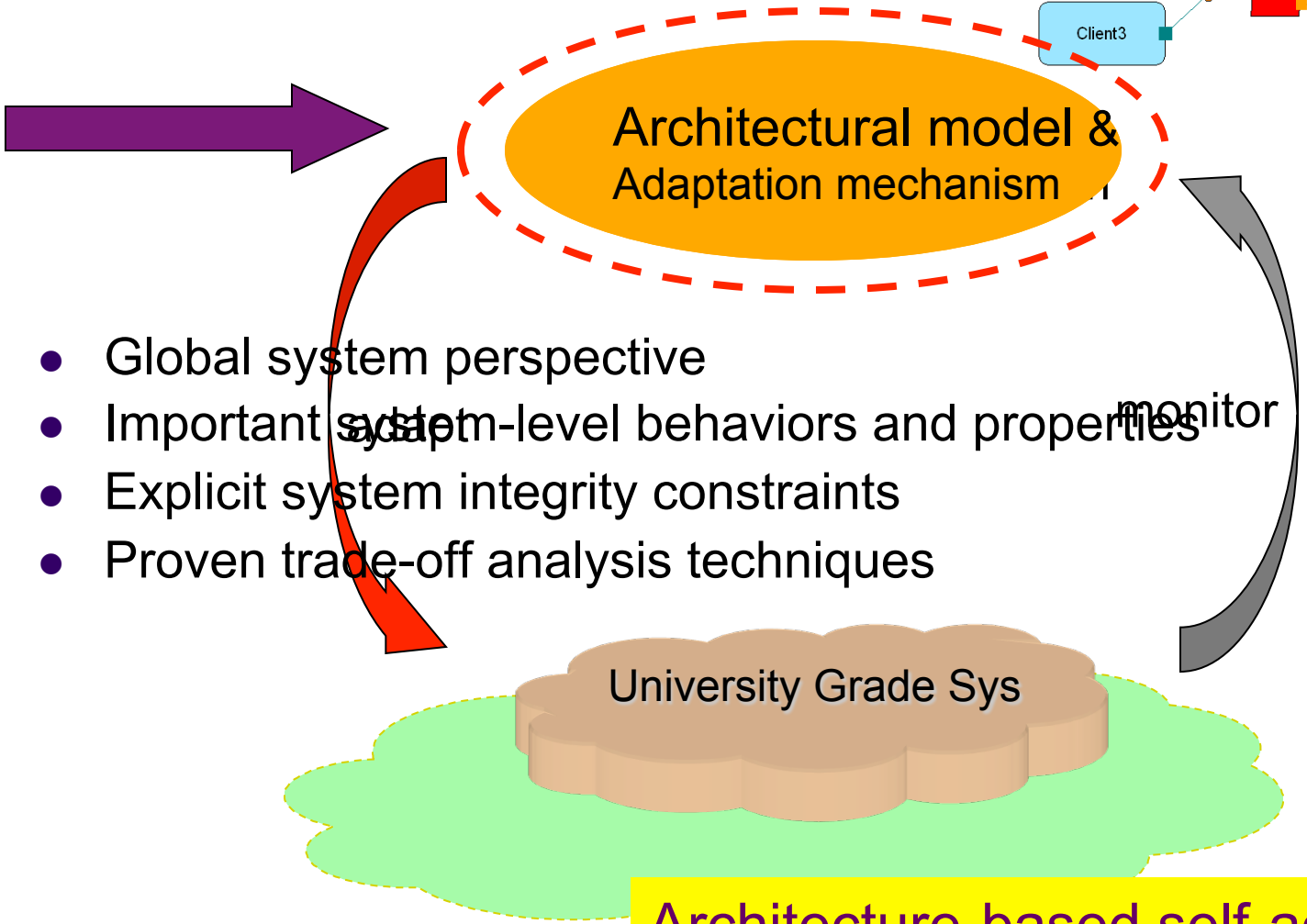
- Detection limited to localized view of system
- Outcome difficult to reason about
- Costly or infeasible to modify existing system
- Difficult to reuse logic for new system

- Exception handling
- Network time-outs
- Signal and interrupt
- Memory management



External Adaptation





- Global system perspective
- Important system-level behaviors and properties
- Explicit system integrity constraints
- Proven trade-off analysis techniques

Architecture-based self-adaptation

Desirable condition for Solution

- Ideally, we'd like a solution that
  - enables software engineers
  - to use architectural models
  - to adapt existing systems

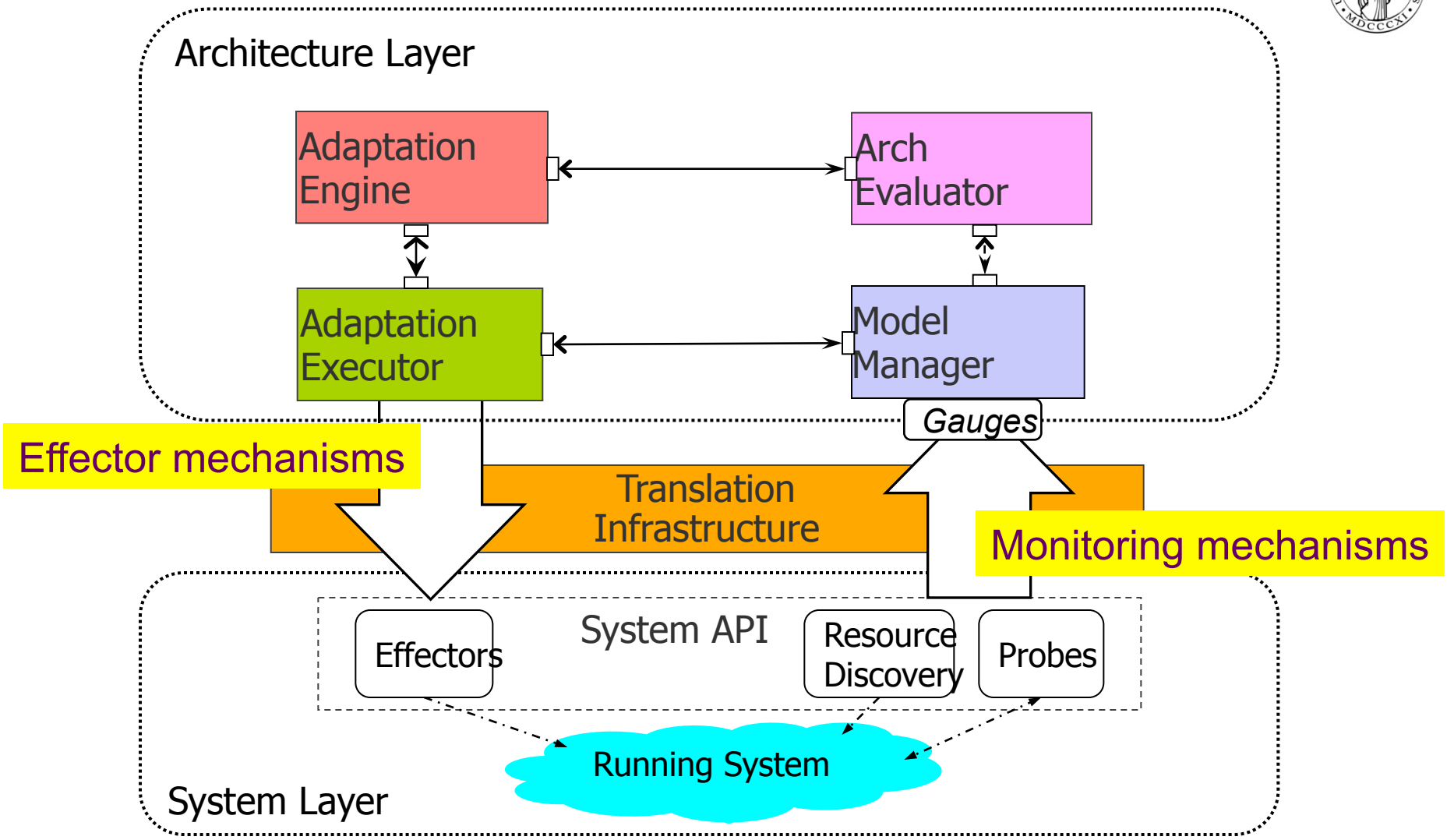
- Key Challenge: One size does not fit all
- Solution should
  - apply to many architecture and implementation
    - *general*
  - facilitate adding self-adaptation capa
    - *cost-effective*
  - support run-time trade-off between multiple adaptation goals
    - *composable*

A family of systems with common element types (e.g., client-server, pipe-filter)

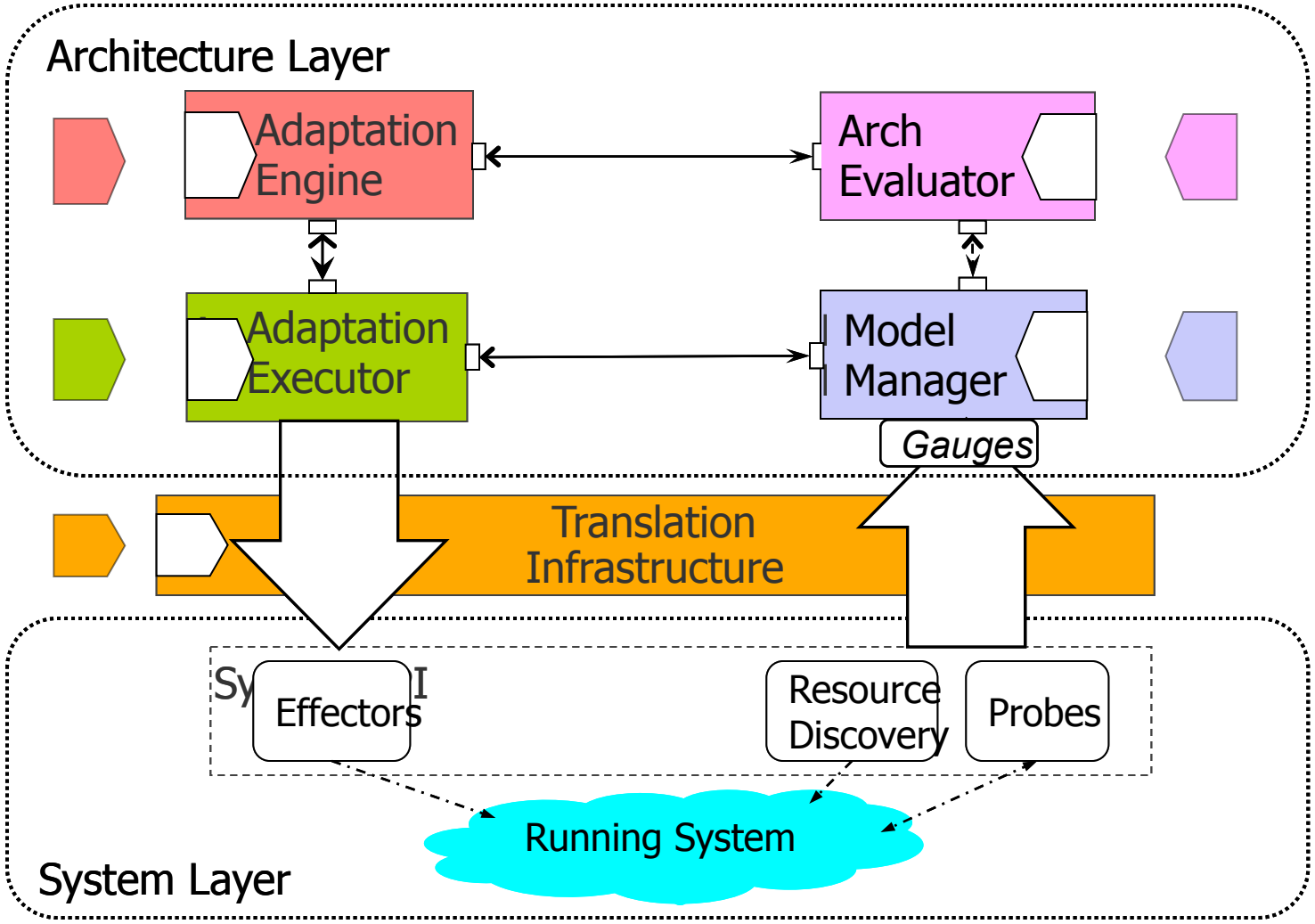
Effort to add self-adaptation is small, e.g., one person within days or weeks

Choice among competing goals based on stakeholder preference

Rainbow Approach



Our *Rainbow* Approach (2)



Architectural style

Characterizes a family of systems related by shared structural and semantic properties

- *Component and connector types* provide a vocabulary of element

  e.g. components:- Database, Client, Server, and Filter; connectors :- SQL, HTTP, RPC,

- *Component* Constraints determine the permitted composition

  e.g. constraints might prohibit cycles in a particular pipe-filter style

- Properties are attributes of the component and connector types.

  e.g., load and service time properties of servers in a performance-specific client-server style

- Analyses can be performed on systems built in an appropriate architectural style.
  e.g. performance analysis using queuing theory in a client-server system

Rainbow extension

- Rainbow extends notion of *architectural style* to *support runtime adaptation* by capturing the *system's dynamic attributes*,
  - In terms of the primitive operations that can be performed on the system to change it dynamically, and
  - How the system can combine those operations to achieve desired effect.

Rainbow as a Tailorable Framework

- General framework with
  - *Reusable* infrastructure + *tailorable* mechanisms

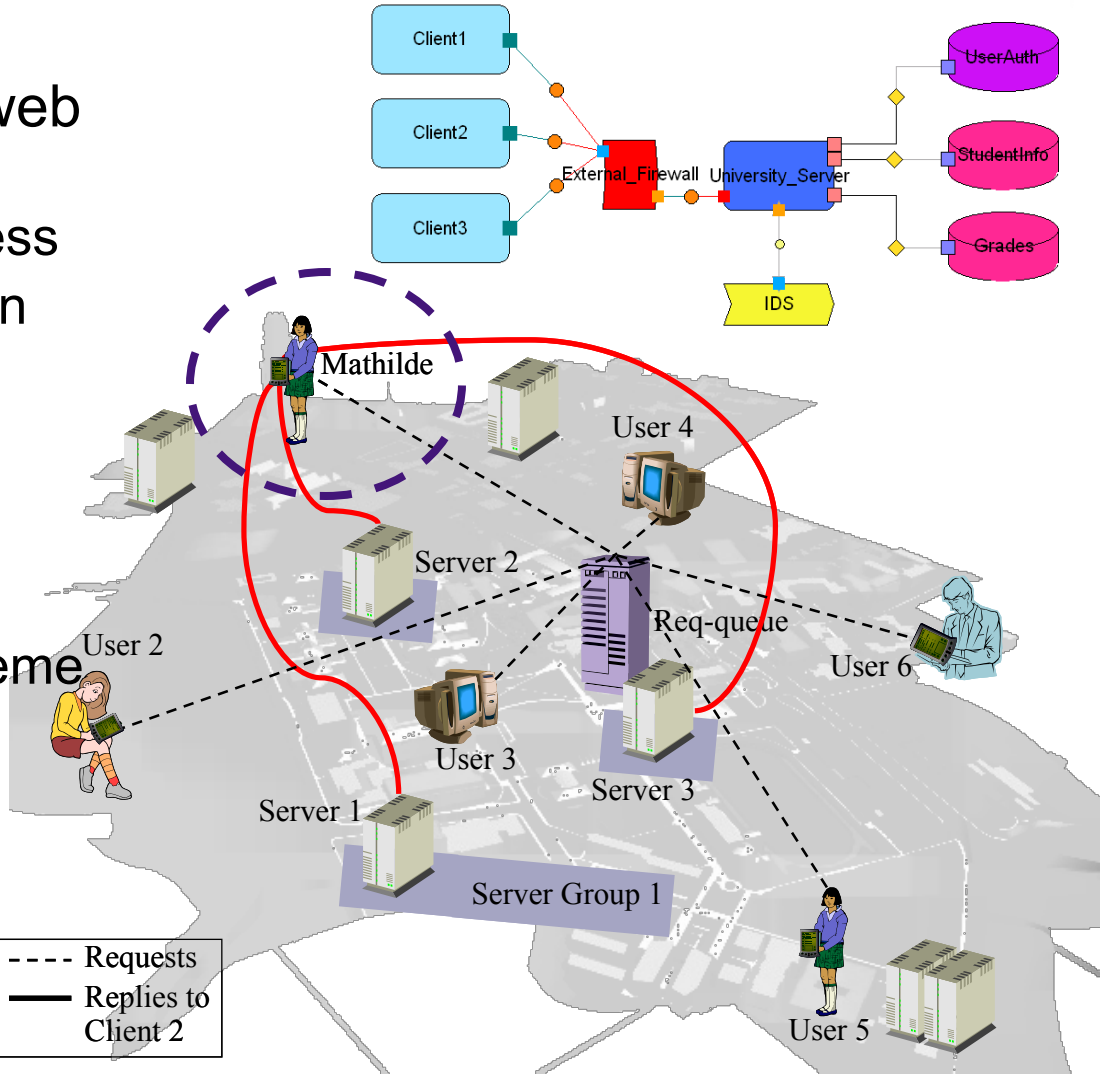
  

  Specialized to targeted
  - system + adaptation goals
- Main components
  - Monitoring mechanisms
  - Model manager
  - Architectural evaluator
  - Adaptation engine
  - Effector mechanisms

What's tailored
Properties
Vocabulary of model
Architectural constraints
Strategies & tactics
Operators

Demo: University Grade System

- Students using university web
  - University aims to provide timely and ubiquitous access
  - One student tries to hack in and change his grades
- Possible (escalating) responses:
  - Turn on auditing
  - Switch authentication scheme
  - Sandboxing
  - Move grades data
  - Close off connections
  - Partition network
  - Turn off services



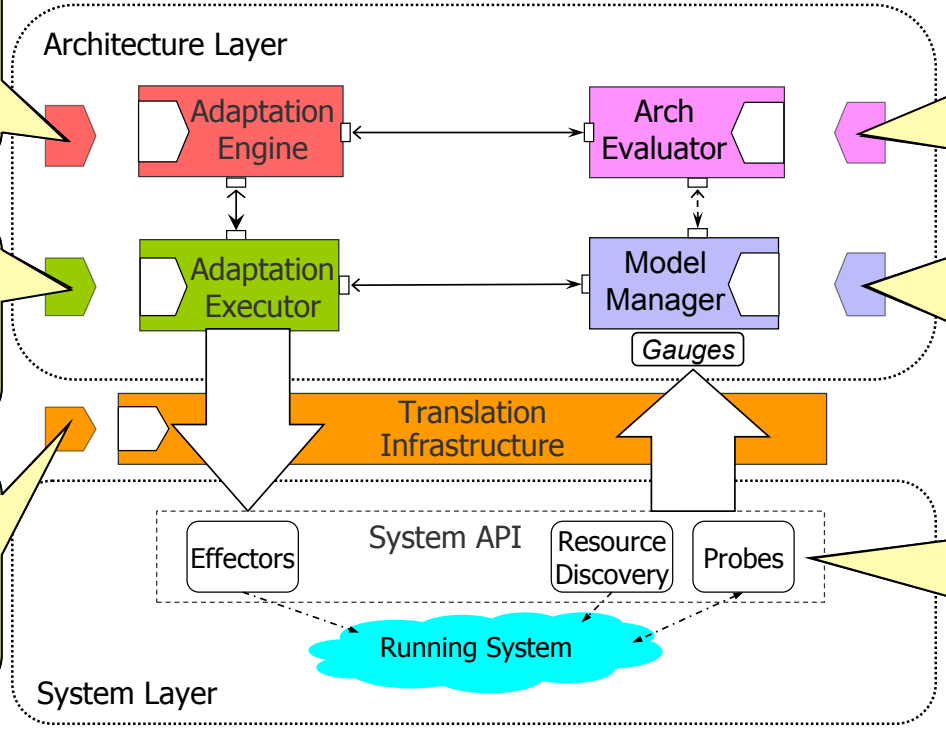
Demo : University Grade System

- Composite system style:
  - Client-server + data repository
- Adaptation goals investigated:
  - Performance + security

counterIntrusion, counterDoS…

GradeServer .addService(), DbT.audit()

Db ⇔ MySQL DB, etc.



Invariant intrusionProb <= threatThreshold

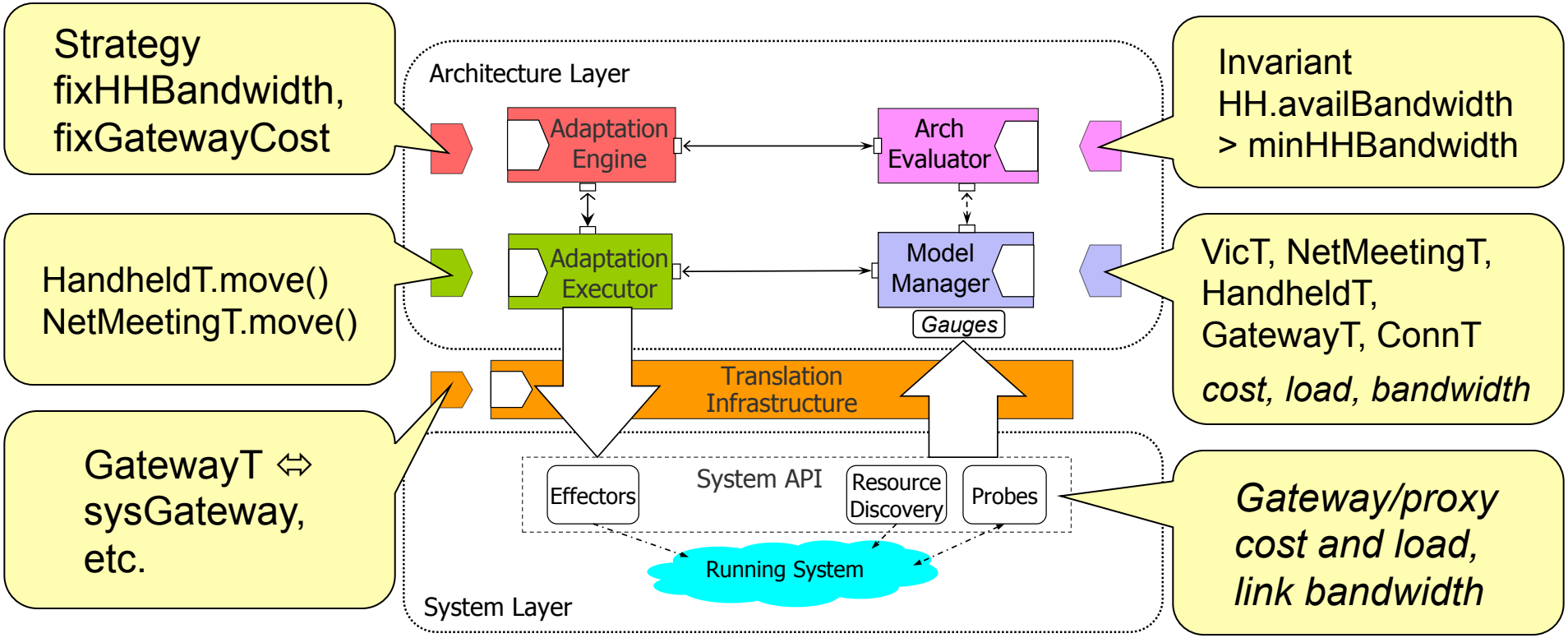
Firewall, Db, ServerT

intrusion%, load

intrusion behavior patterns; specific IDS

Case Study 2: Video Conferencing

- System style: Service-coalition
- Adaptation goals investigated:
  - Performance + cost
- Case study showed:
  - > 90% of framework reuse
  - Need for principled coordination



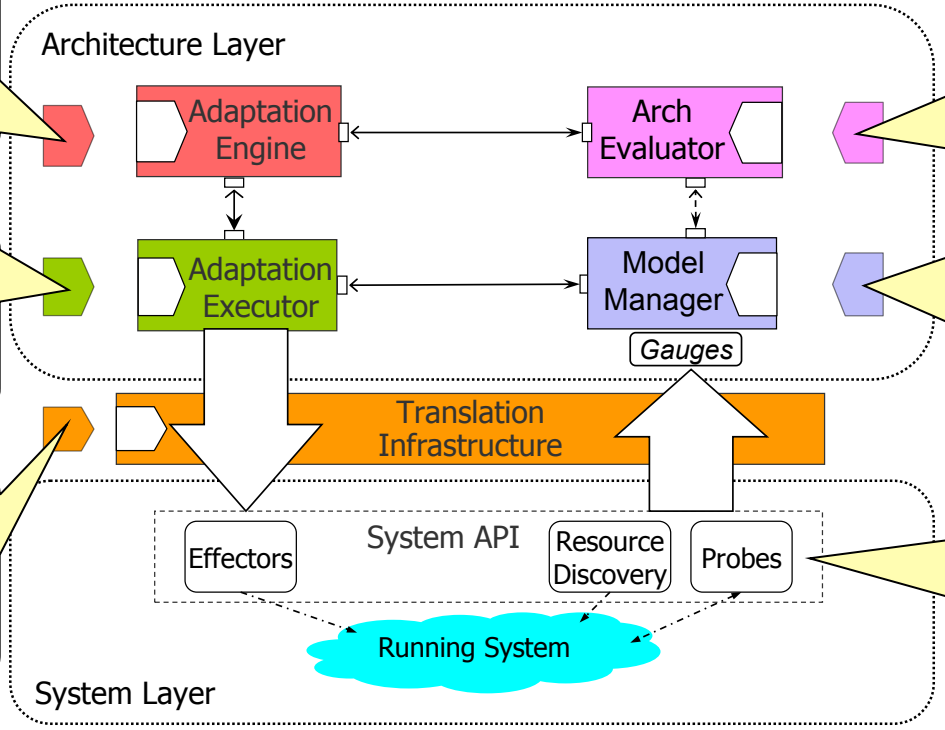
Case Study 3: University Grade System

- Composite system style:
  - Client-server + data repository
- Adaptation goals investigated:
  - Performance + security

Strategy counterIntrusion, counterDoS…

GradeServerT .addService(), DbT.audit()

DbT ⇔ MySQL DB, etc.



Invariant intrusionProb <= threatThreshold

FirewallT, DbT, ServerT, SSHT

intrusion%, load

intrusion behavior patterns; specific IDS

Preliminary Work Shows Promise

- Rainbow prototype
  - Integrated mechanisms and tested control cycle
  - Demonstrated usefulness for specific adaptation scenarios
- Two case studies
  - Three styles of system
    - Client-server, service-coalition, data repository
  - Three kinds of adaptation goals
    - Performance + security + cost
- Adaptation language under development

Conclusion

- Rainbow relies on existing capabilities in the managed system to allow system states to be extracted and changes to be effected.
- Using a software architecture model allows the adaptation engineer to abstract away unnecessary details of the managed system.
- The software architecture of a system is the structure of its **components**, their **interrelationships**, and **principles**
- Allows an engineer to
  - obtain a global system perspective,
  - explicitly capture system properties and constraints, and
  - leverage existing, proven architectural analysis techniques to determine problems and remedies

Some Research Problems

- Architectural “recovery” at run time.
- Efficient, scalable constraint evaluation
- Environment modeling and scoping
- Handling multiple models and dimensions of concern
- Reasoning about the correctness of a repair strategy
- Non-deterministic arrival of system observations
- Avoiding thrashing
- Adapting the adaptation strategies

Quiz

- What does Rainbow add in Architectural evaluation ?
- Answer
- Can Adaptation executor directly take inputs from Probes? Why it can or it can’t?

Critics

- Architectural changes, can be highly effective, but very hard to implement, test, and manage
  - Specially in complex large-scale distributed systems.
- *Fallback*:- Large-scale applications stability is major challenge. Specially under unanticipated conditions.
  - Dynamic change may lead to unanticipated conditions.
  - No recovery design
- Evolution is not clear.

Future direction

- Multi objective adaption
- Collaborative Adaptation cycle
- Dynamic update of strategies and strategy selection information
- Parallel adaptation
- Adaptation re-emption
- Real time adaption

The END